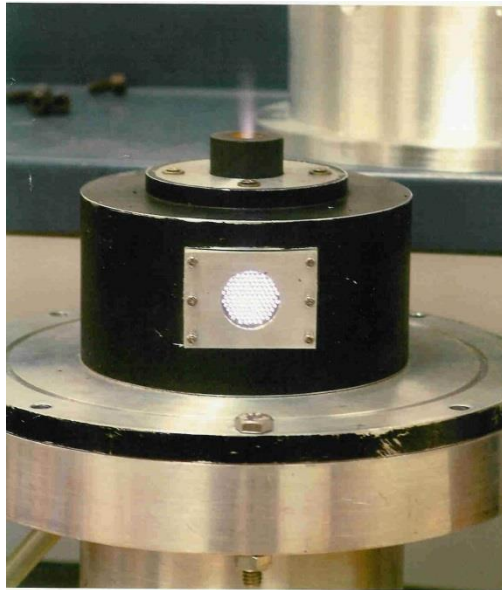


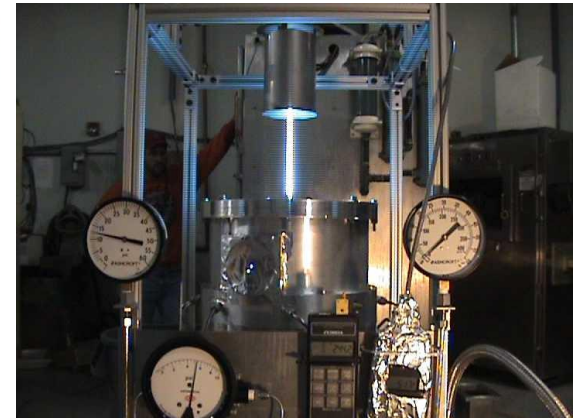
# The MET (Microwave Electro-Thermal) Thruster With Water Vapor Propellant and Mars Missions



**John Brandenburg**



Morningstar PROPRIETARY DATA



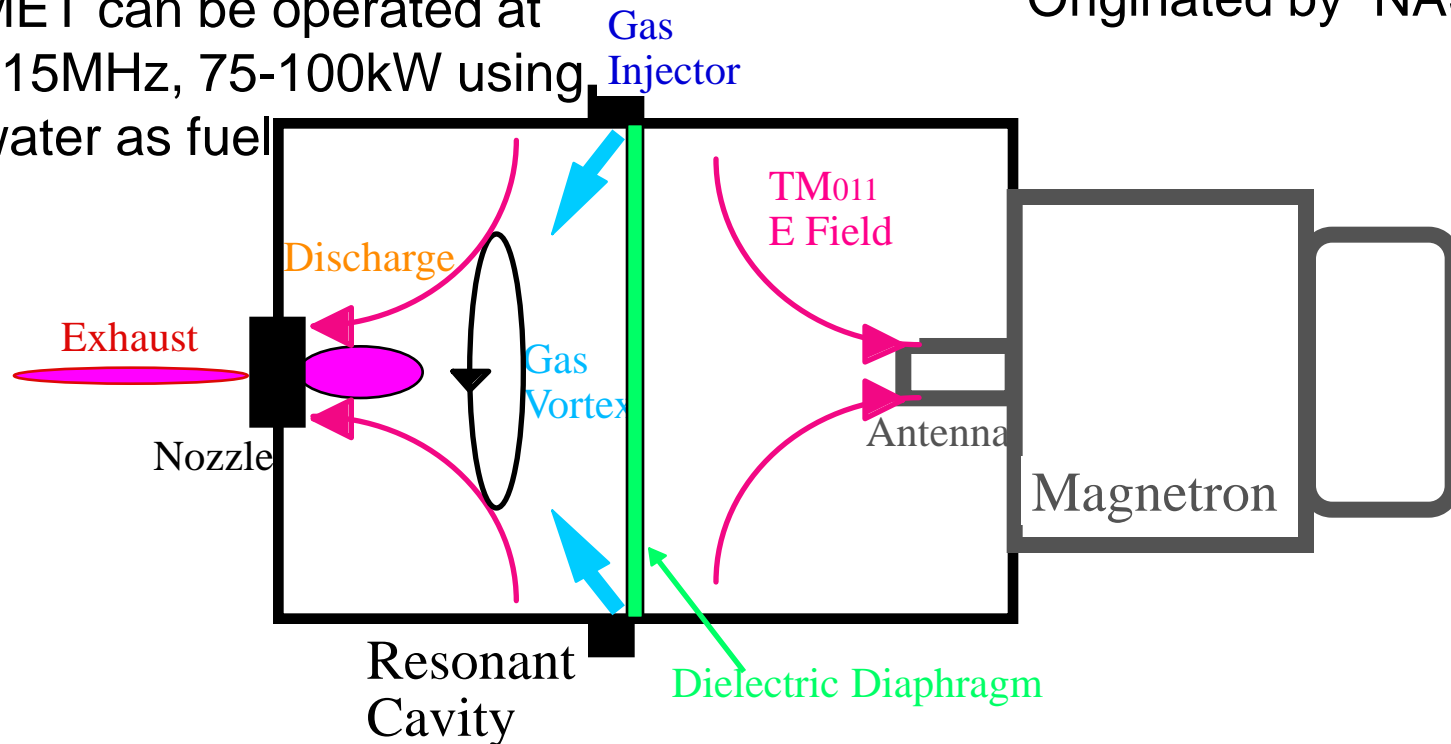
# Agenda

- The MET Thruster With Water Propellant
- The MET and Evolving Space Transportation
- The MET and Mars Missions
- Summary



# MET Thruster

- MET is an electrodeless arc-thruster with high thermal efficiency
- MET can be operated at 915MHz, 75-100kW using water as fuel
- 915Mhz can be generated at 95% efficiency
- Originated by NASA



# MET Using Water As Fuel

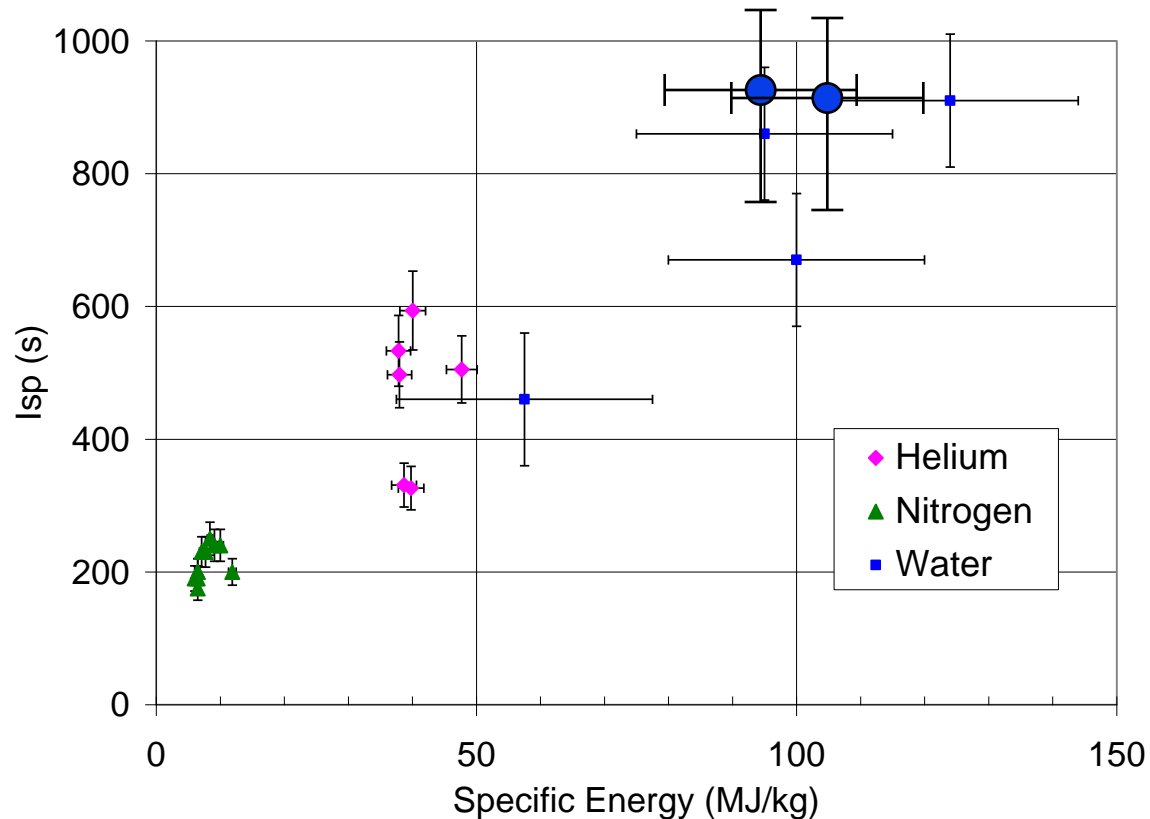
- H<sub>2</sub>O Fueled MET First Developed and patented by Author at RSI
- $I_{sp} \geq 800$  sec achieved in high pressure discharges
- High  $I_{sp}$  apparently derived from rapid recombination of O and H in nozzle ( H<sub>2</sub>O disassociates in plasma)
- High  $I_{sp}$  at high chamber pressure ( $P > 600$ torr) confirmed by Aerospace Corporation (428sec)
- High H<sub>2</sub>O content of plume recently confirmed by Aerospace Corporation
- MET is only device that can achieve high water  $I_{sp}$  because of electrodeless operation

# High Pressure Discharges

---

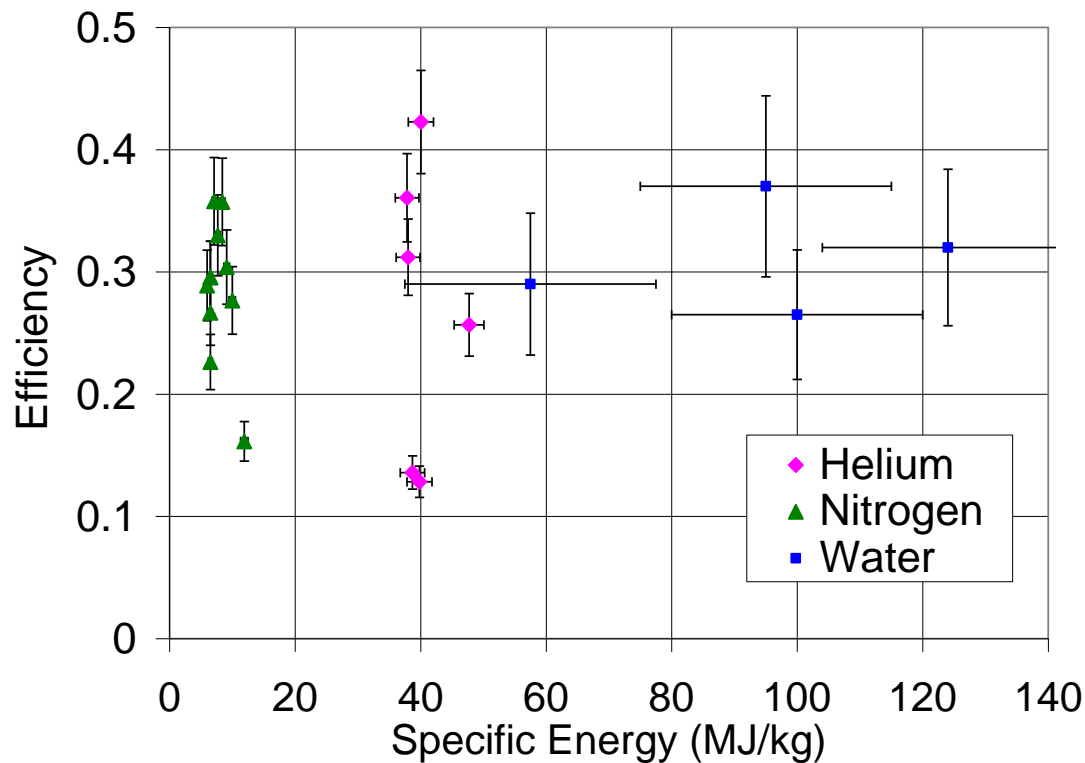
- High pressure discharges  $P > 500$  Torr essential to high water performance
- High pressure increases plasma collisionality and electrical resistance
- High pressure increases H, O recombination rate
- High pressure water discharges first run by author

# MET-1000 Isp Performance



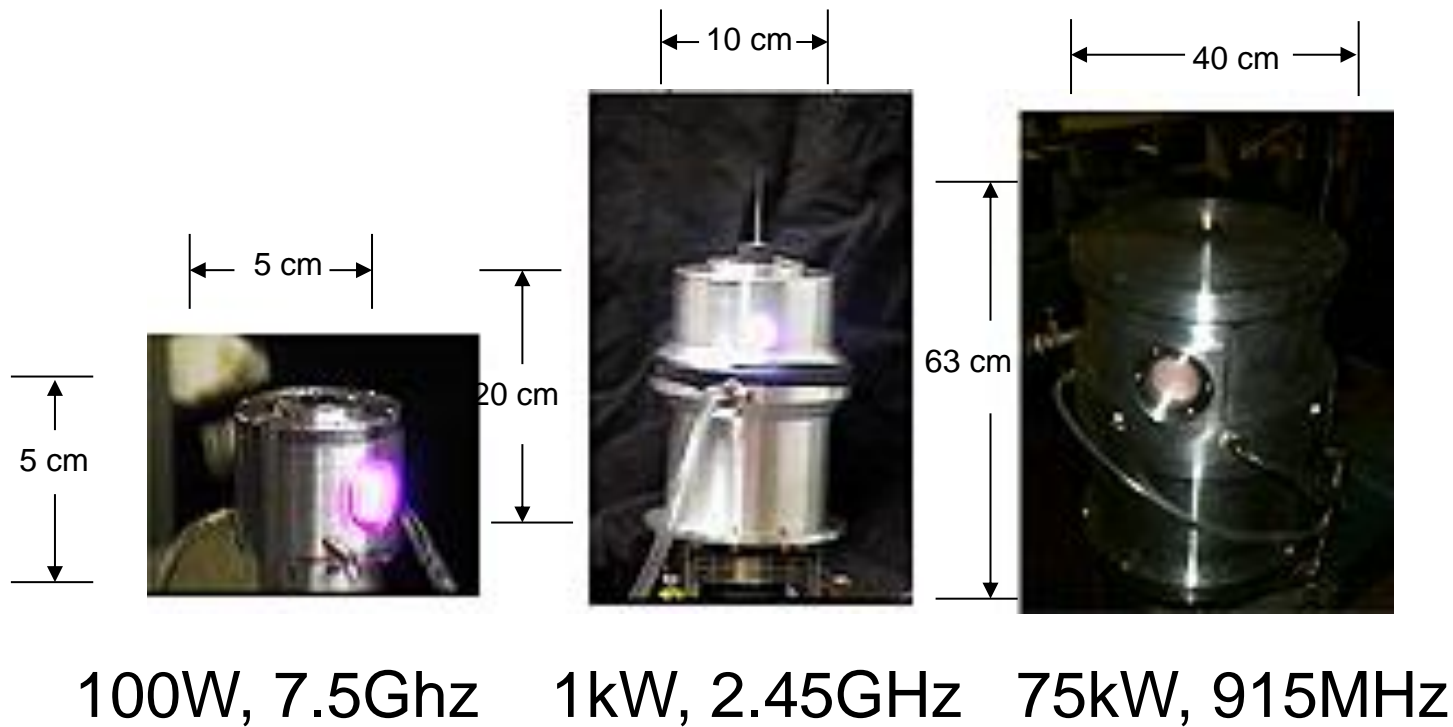
- Boiler weighing
- Continuous flow vaporizer

# MET-1000 Efficiency Performance



Similar efficiency  
For differing gases  
suggests optical  
radiation losses

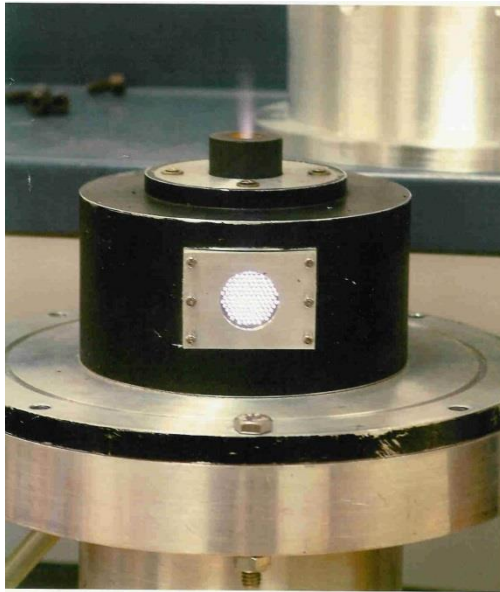
# MET Scaling



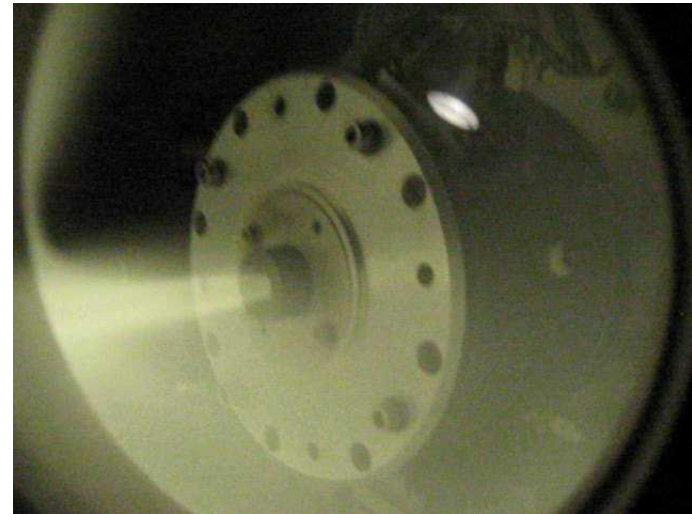
Nitrogen discharges



# MET Atmospheric Pressure Water Discharge

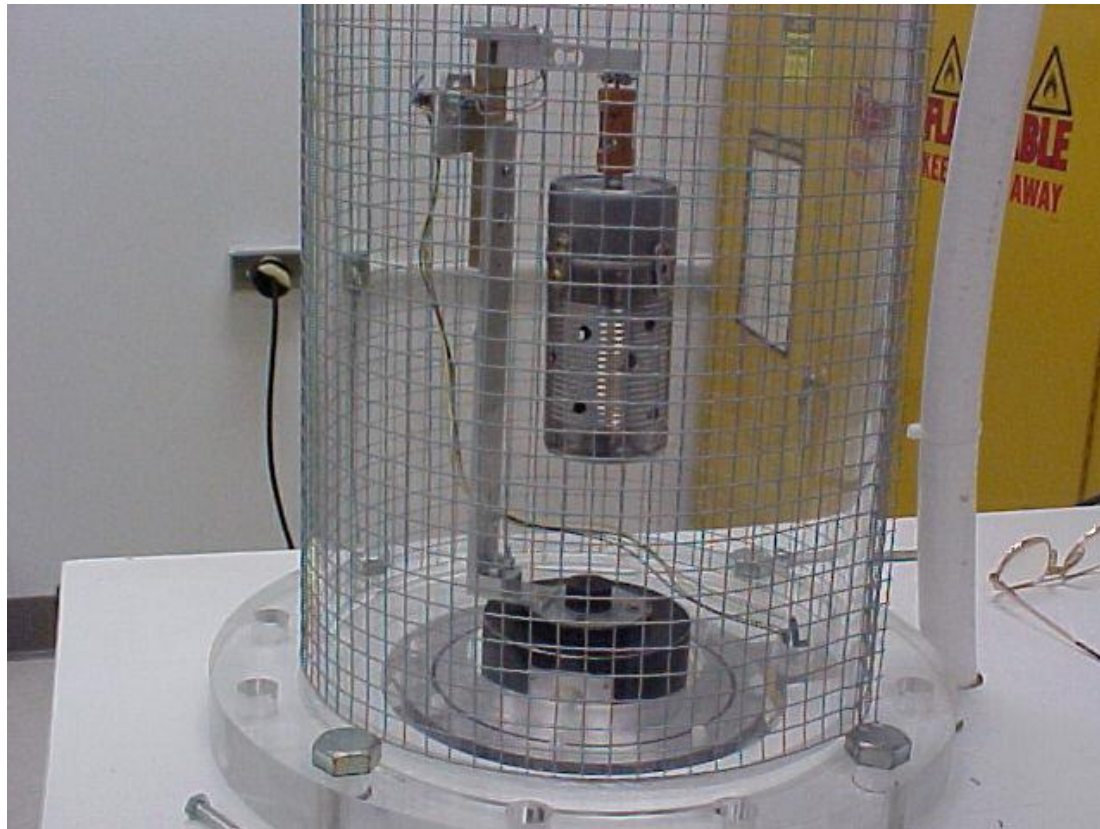


Water Vapor in  
room air

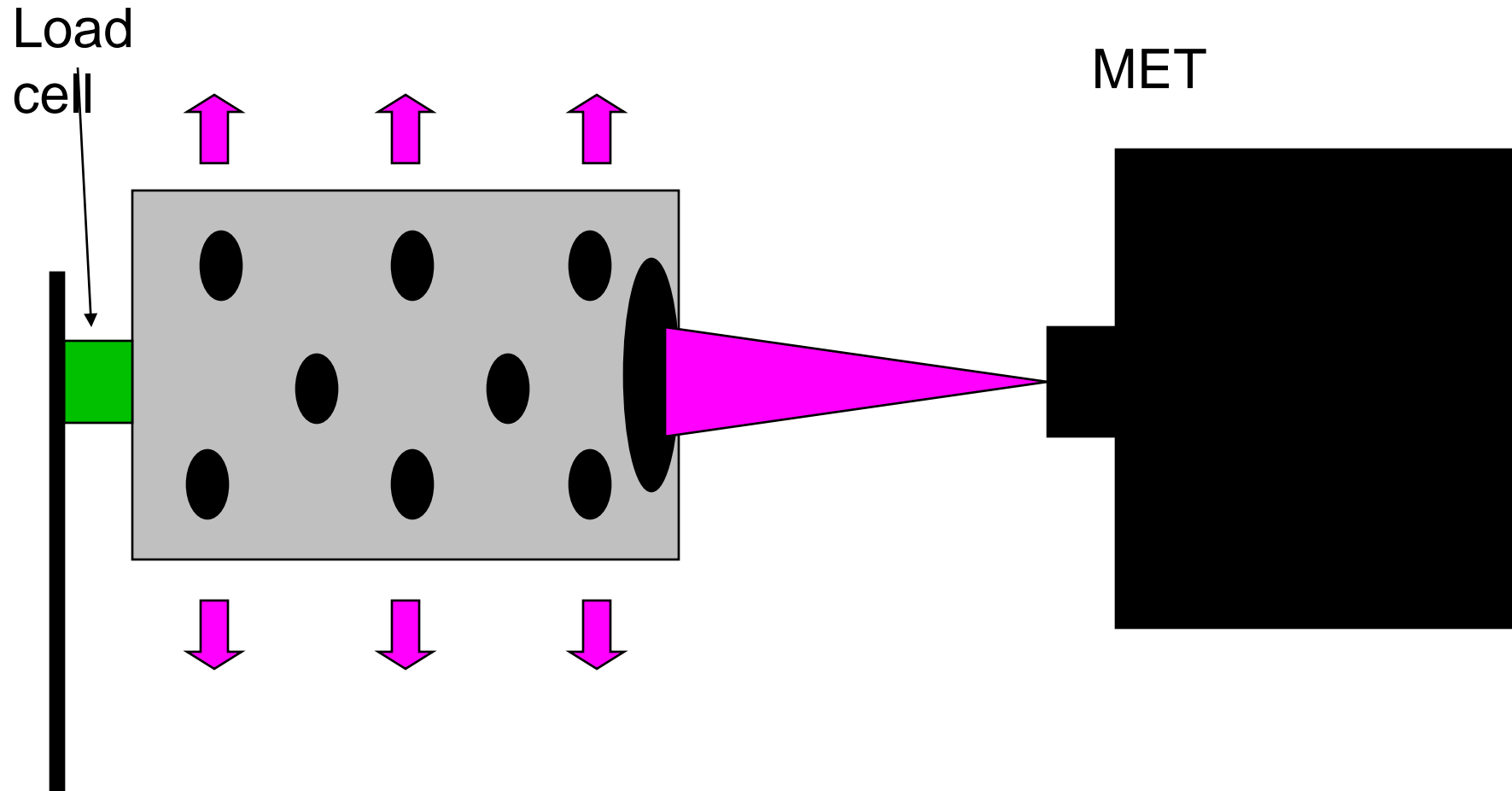


Nitrogen in vaccum

# Thrust Experiment



# “Chinese Fish Trap” Thrust Cell

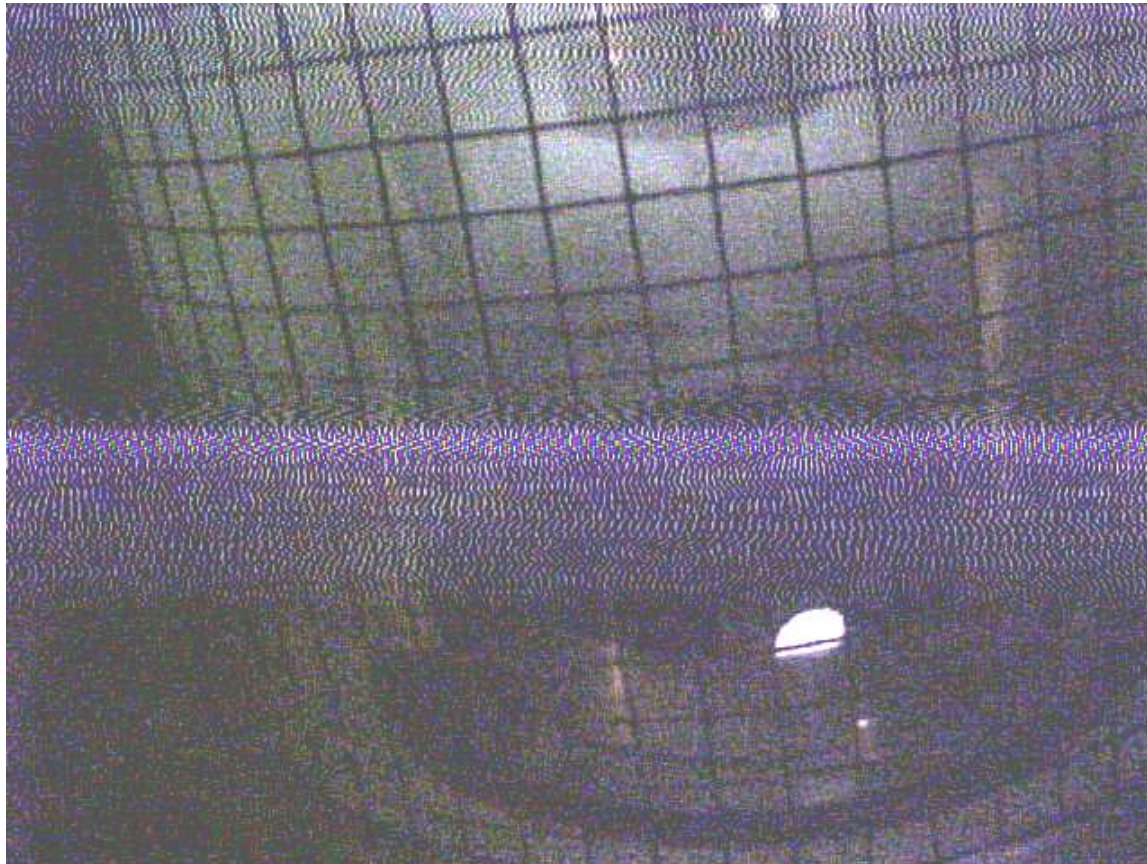


# Nitrogen Thrust Experiment

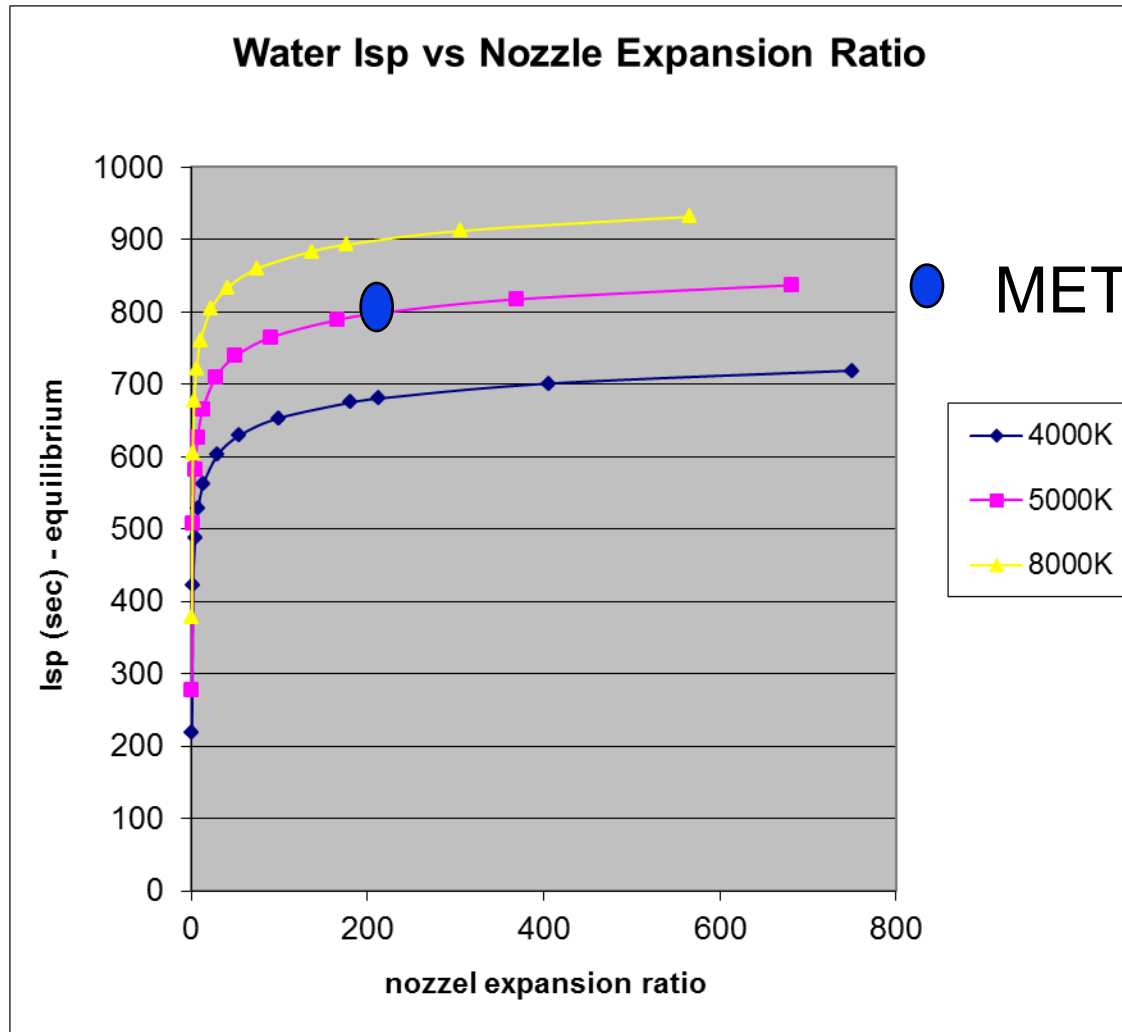




# Water Vapor Thrust Experiment



# McBride Code Results



# 75 kW MET Thruster Hardware



915 MHz  
Generator



MET attached  
to Waveguide

Pioneered by John Powers of NASA



# 75 kW MET Thruster Hardware

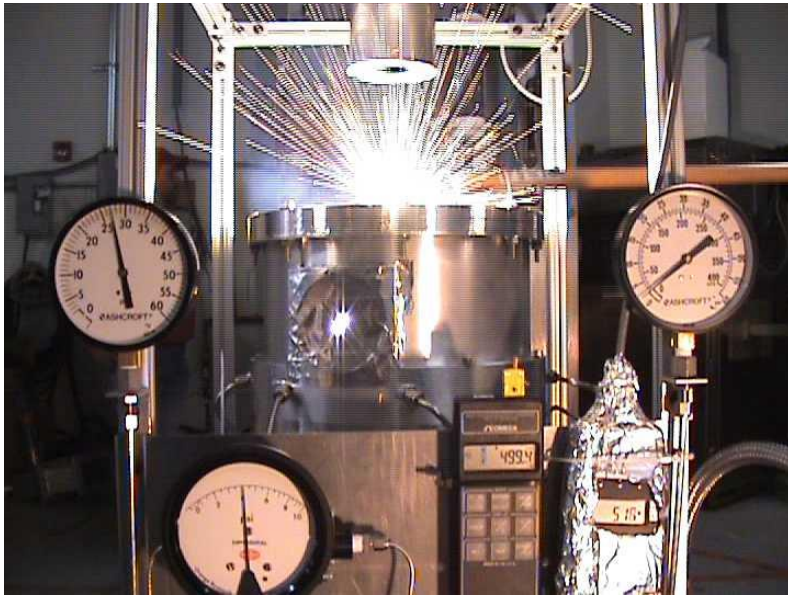


MET attached  
to Waveguide

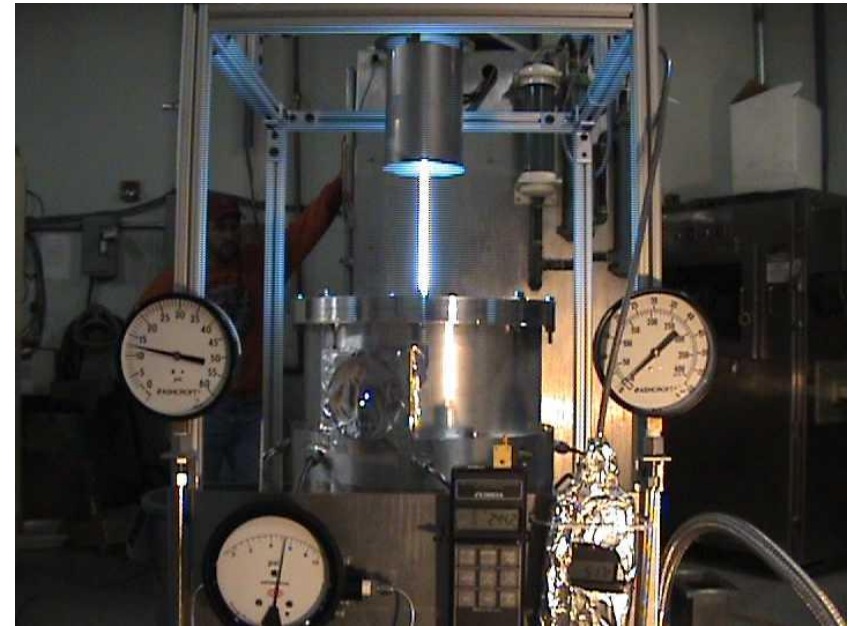




## MET 75kW running on Water Vapor

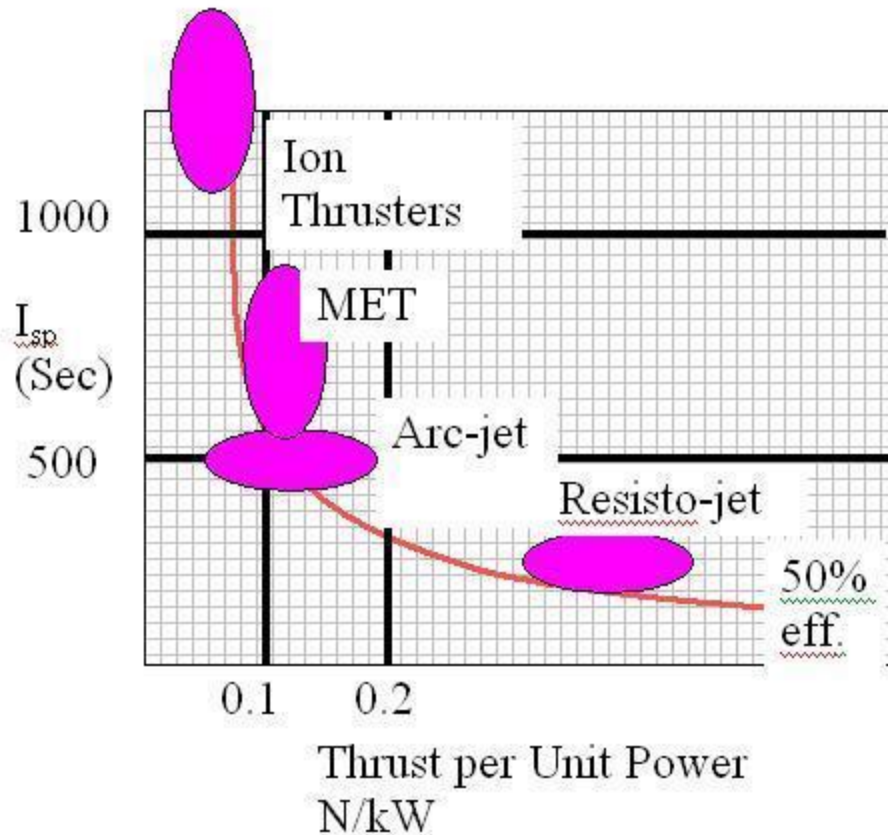


Ignition!



Running on Water Vapor

# MET in Relation to Other Electric Propulsion Technologies



$$K = \eta W$$

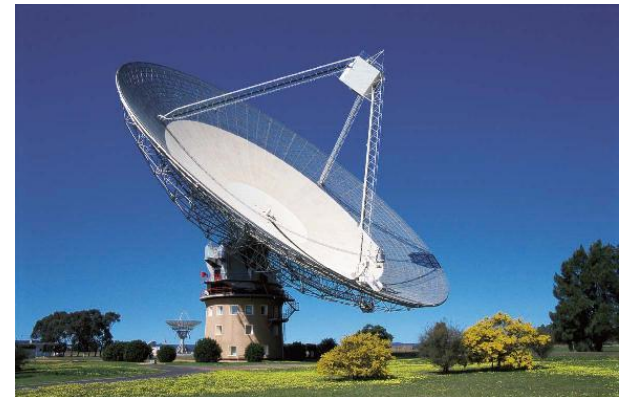
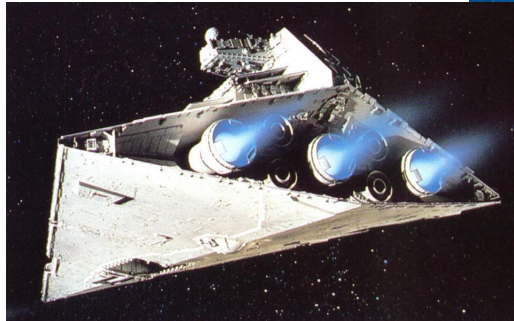
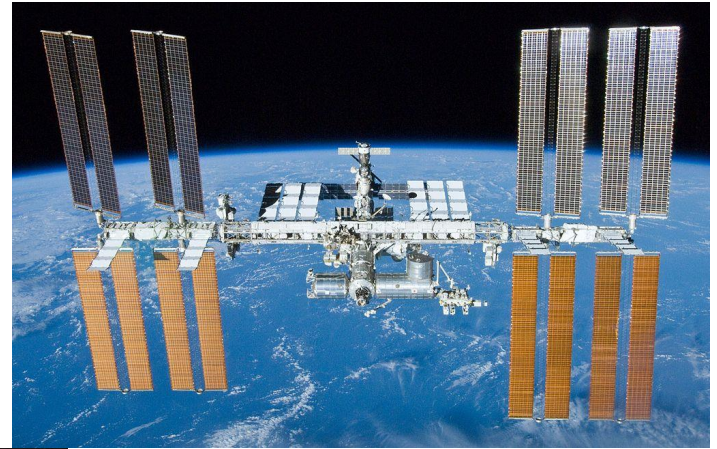
Kinetic power efficiency  $\eta$

$$I_{sp} = \frac{V_{ex}}{g}$$

$$\frac{T}{W} = \frac{2g\eta}{I_{sp}}$$

**Thrust per unit power is reciprocal to  $I_{sp}$**

# MET –H<sub>2</sub>O and Evolving Space Transportation



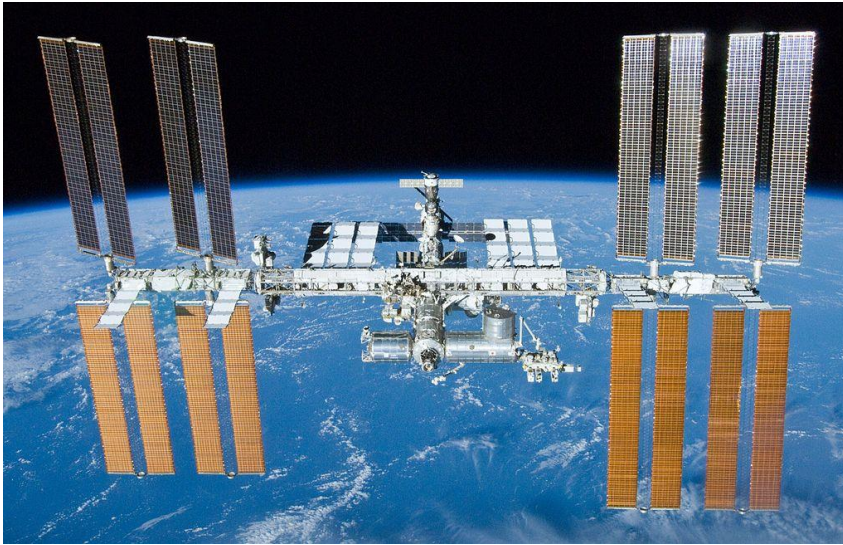
# Fuel Depots



Both Mars and the Moon Have Abundant Water



# SEP (Solar Electric Propulsion)



MW class Solar Arrays  
can allow high thrust  
MET missions

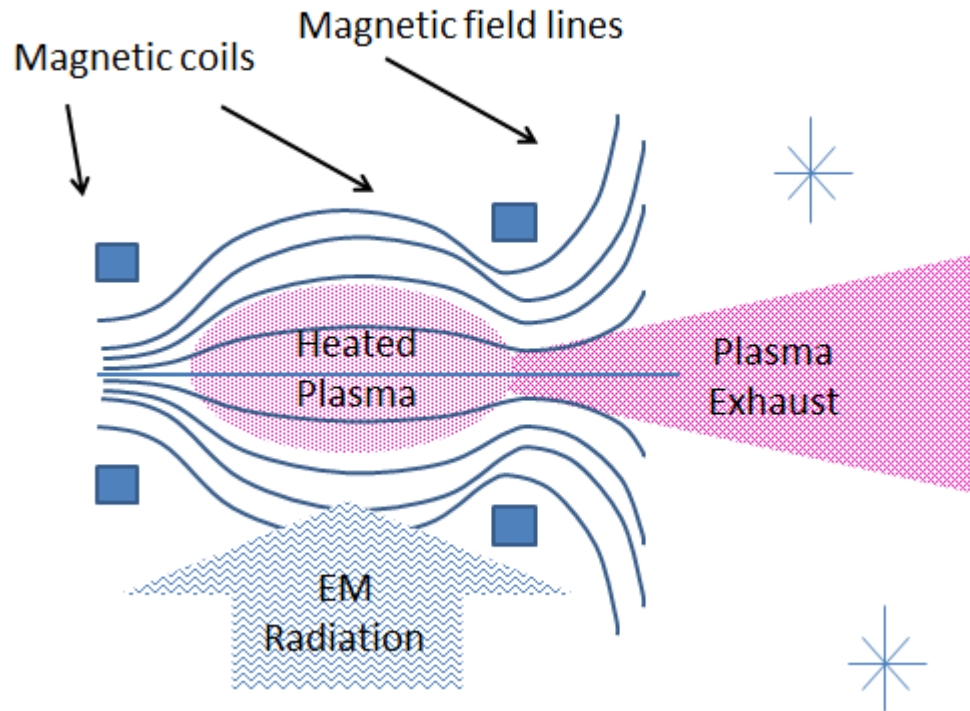
168 kW ( full sunlight)

# Beamed Power



MET is very compatible with beamed power

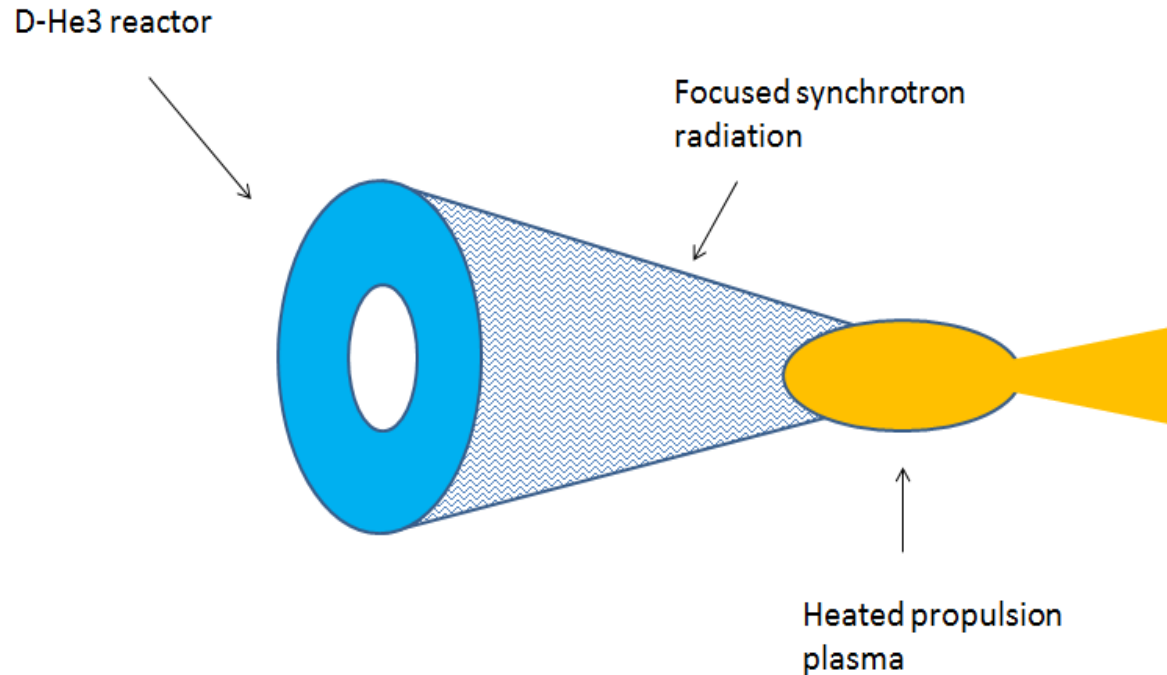
# Ultimate Microwave Rocket Engine



VASIMIR-like Concept

## Future : SRF(Synchrotron Radiation Fusion Drive)

First proposed to NASA Synthesis Group Brandenburg (1992)



“SRF” Drive , Brandenburg, with Santarius et al. AIAA (1996)



# New Architectures Possible

---

- MET –H<sub>2</sub>O has higher than chemical  $I_{sp}$
- Water is abundant, easy to store, and easy to transfer in space
- Water is useful for rad-shielding and life support

# ***Morningstar DSR (Deep Space Rendezvous)***

## **Mars Mission Architecture**



# ***Morningstar DSR*** Mars Mission Architecture

- Builds on earlier ***Solaris*** architecture
- Uses much higher than chemical  $I_{sp}$   
MET-H<sub>2</sub>O for main propulsion
- Uses ease of water transfer in space
- Crew safety maximized by separation  
of TMI (Trans Mars Injection) burn from  
LEO departure

# ***Morningstar DSR cont.***

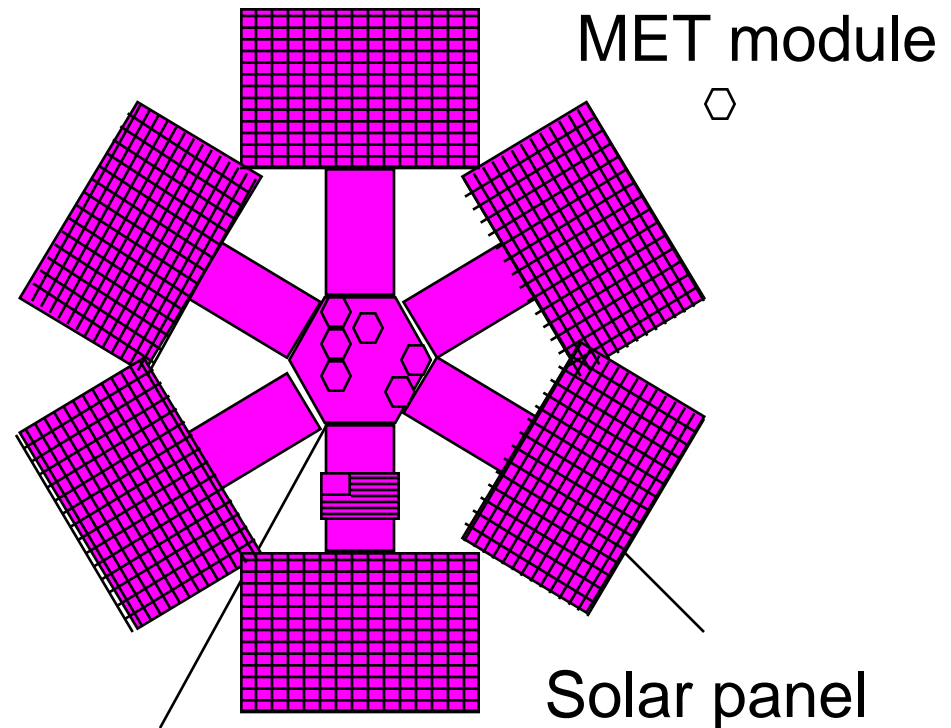
---

- Main Crewed Vehicle with SEP unit and water propellant launched by SLS and goes into 2 month free return orbit
- Deep Space Rendezvous With Previously Launched automated Cargo-Water Tanker
- Transferred Water Propellant Allows Deep Space TMI burn using SEP

# ***Morningstar DSR basic vehicle***

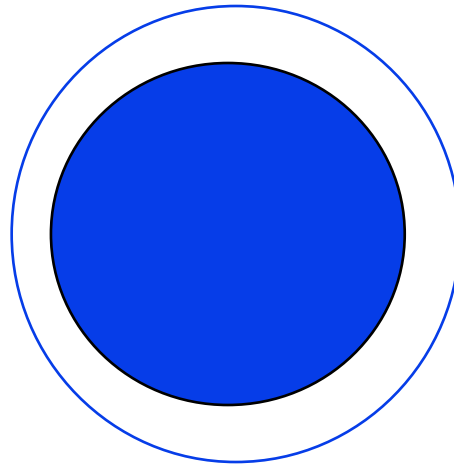
300kW 2 ton SEP  
propulsion unit  
(dry weight)

Multiple MET  
propulsion units



Vehicle("snowflake")  
core (fuel tanks, living quarters)

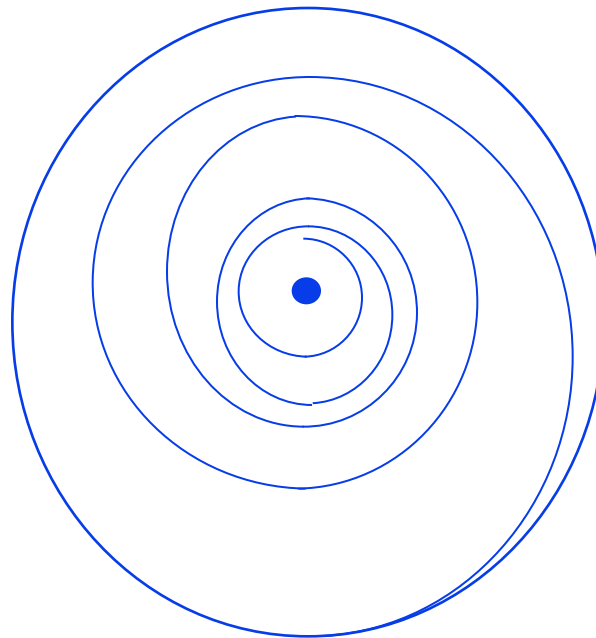
# Phase 1



SEP tanker-cargo vehicle loaded and fueled in LEO  
by Cygnus derived vehicles bringing up water and  
cargo

# Phase 2

Cargo-tanker  
spirals out to  
deep space orbit



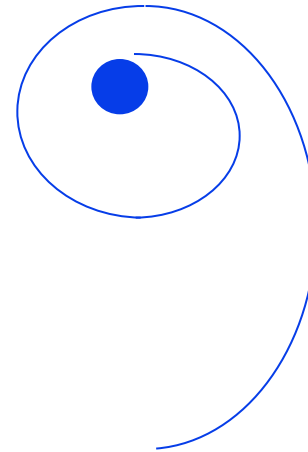
Pure MET ( low  
thrust)

# Phase 3

Crewed Mars vehicle  
launched on SLS



Impulse (High thrust) plus SEP (low thrust) outside of Van Allen belts

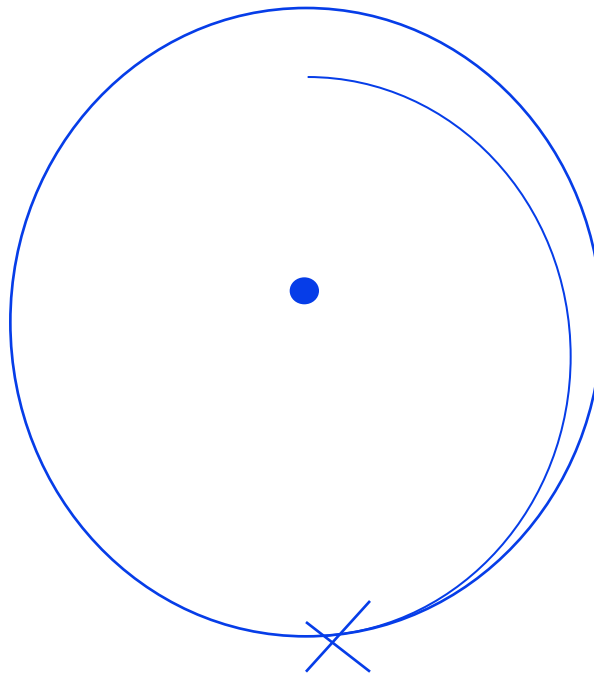


Vehicle put on 2 month free-return orbit



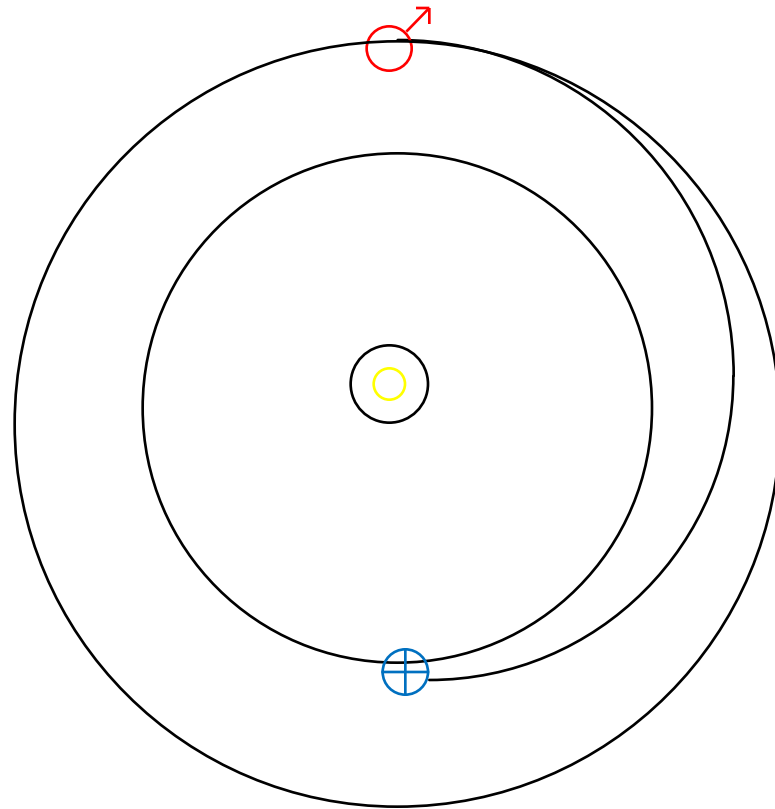
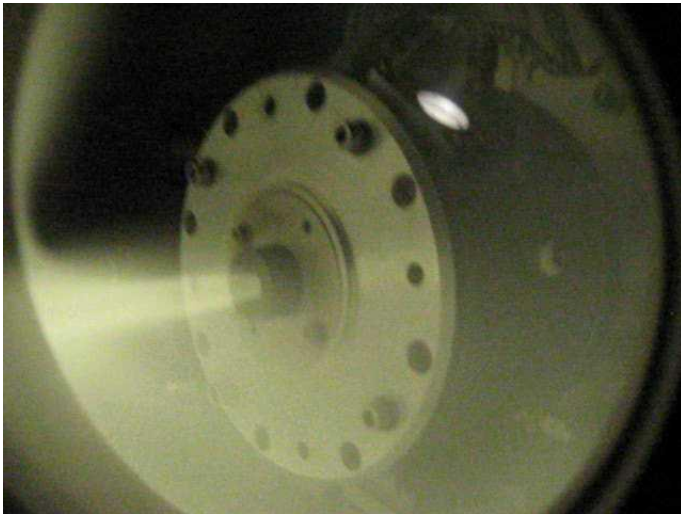
# Phase 4

Deep Space  
Rendezvous  
with water and  
cargo transfer



# Phase 5

TMI burn using  
SEP in Deep  
Space



# Summary

---

- The MET thruster performance on water has been measured as 800sec , apparently due to hydrogen oxygen recombination in the nozzle
- MET thruster is now ready for engineering development for space flight testing
- MET-H<sub>2</sub>O propulsion system can allow DSR architecture for Mars with propellant transfer and TMI separate from LEO departure
- ***Microwave plasma propulsion has a great future !***

# The Future

